



Delineation of Near-Surface Structural Features Suitable for Groundwater Accommodation Using 1-D and 2-D Resistivity Methods in Igarra, Akoko-Edo, Southwestern Nigeria

¹SALAMI, AS; ²BABAFEMI, EM

¹Department of Geology University of Benin, Edo State, Nigeria

²Geobabs Integrated Services, Lagos, Nigeria

*Corresponding Author Email: emmanuelmuyiwa32@gmail.com

ABSTRACT: Electrical resistivity methods using dipole-dipole and Schlumberger configurations of Vertical Electrical Sounding (VES) were carried out to evaluate the near-surface structural and lithological features suitable for groundwater development in parts of Igarra, Southwestern Nigeria. Two profiles with lengths of greater than 350m were carried out. A total of fifteen sounding locations along the profile lines were occupied. Dipole-dipole data were interpreted using DiprofWin software while interpretation of the VES data followed two stages of qualitative and quantitative data interpretation using Resist software. Dipole-dipole interpretation results indicate the occurrence of local fractures while VES interpretation results reveal the typical basement rock profile ranging from topsoil, lateritic sand, weathered front, fractured to fresh basement. The significant variations in terms of persistence and thicknesses of these basement vertical rock profiles were revealed by the geoelectrical correlation panels, which indicate typical basement inhomogeneities over short distances. The local structural domains, the weathered front (where thick) and the fractured basement are demonstrably potential sources of groundwater, at least for domestic and small scale enterprises in this part of Igarra.

DOI: <https://dx.doi.org/10.4314/jasem.v24i7.13>

Copyright: Copyright © 2020 Salami and Babafemi. This is an open access article distributed under the Creative Commons Attribution License (CCL), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Dates: Received: 16 May 2020; Revised: 29 June 2020; Accepted: 07 July 2020

Keywords: 2-D Pseudosection, Dipole-dipole, Fracture Basement, Vertical Electrical Sounding

Igarra and environs are underlain by crystalline basement rocks and groundwater is usually contained in the weathered or fractured basement rocks, and near-surface features of hydrogeological significance. Groundwater occurrences in the crystalline basement terrain can be very irregular due to rock mass heterogeneities which may include abrupt discontinuity in lithology, thickness, and electrical properties of the overburden and weathered bedrock (Satpathy and Kanugo, 1976; Offodile, 1983; Olorunfemi and Fasuyi, 1993). Consequently, groundwater exploration within such geologic settings requires integration of geological/geophysical data sets to effectively characterize the hydrogeologic zones and to enhance successful identification of well locations. Electrical Resistivity (ER) has been used by various workers around the world to delineate near-surface geologic structures, (Salami and Babafemi, 2017; Soupios *et al.*, 2007; Adeoye-Oladapo and Oladapo, 2011) some of which could accommodate groundwater. This method reveals subsurface geologic variations at a reasonable cost and with significant precision, (El-Kaliouby and Abdalla, 2015). Schlumberger (VES) and Dipole-Dipole (profile) arrays widely used for 1-D and 2-D electrical resistivity surveys were employed in this work in order to delineate zones that could serve as sites for groundwater accumulation, which is considered today as the largest available reservoir of fresh water,

(Adepelumi, *et al.*, 2013). Groundwater is increasingly becoming more desirable than other sources for domestic and industrial uses because of its cleanliness and for the fact that borehole yields are often sufficient to meet specific needs especially when the boreholes are optimally located and constructed (Salami and Babafemi, 2017). The demand for potable water for domestic, agricultural and industrial uses has grown over the years in Igarra and environs due to increase in population and the emergence of some small to medium scale industrial activities. This study therefore, aims at prospecting for groundwater productive zones in a part of Igarra, like many other parts, characterized by high borehole failures, through the definition of spatial orientation and distribution of basement fractures. The study also intends to show the efficacy of resistivity methods in delineating features that are potential aquifer habitat thus increasing groundwater yield potentials.

Location, Brief Geology and Hydrogeology: Igarra is the headquarters of the Akoko-Edo Local Government Area of Edo State, Southwest of Nigeria. The town is made up of Ugbogbo, Utua, and Uffa quarters. It is characterized by rocky terrain, and is topographically flanked to the east by the famous Kukuruku hills. The study area is located around Bokeshimi and Amore areas in Ugbogbo quarters. Geographically, the work area is approximately located within latitude 007° 16'

*Corresponding Author Email: emmanuelmuyiwa32@gmail.com

30°N to 007° 17' 30"N, and longitude 06° 05' 15"E to 06° 07' 15"E (Figure 1). Igarra and environs are located within the Basement Complex of Southwestern Nigeria. Several authors, notably, Oyawoye, (1964); Rahaman, (1976); Rahaman, (1989); Odeyemi, (1999); Boesse and Ocan, (1992) and Anifowose, *et al.*, (2006) have discussed aspects of the geology of the Basement Complex of Nigeria such as evolution, tectonics and lithology.

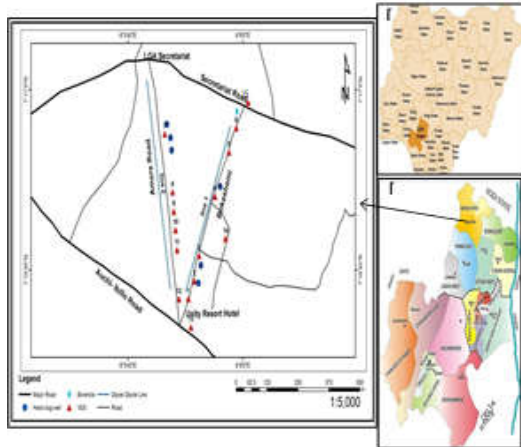


Fig 1: Location Map of the Study Area within Igarra Town. Inset: (a) top: Edo State, Nigeria. (b) bottom: Igarra, Akoko-Edo Local Government Area. (Courtesy: Google Maps).

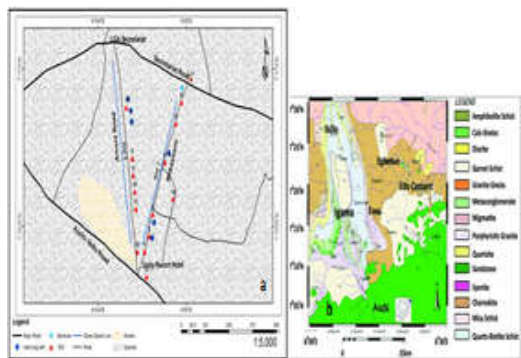


Fig 2: Geological Map of Study Area. a: Local Site Geology; b: Geological Map of Igarra and Environs (after Anifowose *et al.*, 2006)

Basically, Igarra and environs are underlain by the slightly migmatized to unmigmatized schist belt which is underlain by the Migmatized–Gneiss Complex with the entire suit intruded by the Pan-African Older Granites. The Igarra schist belt (Figure 2b) which runs for about 60 km in a generally NNW–SSE direction lithologically consists of quartz-biotite schist, mica schist, quartzite and quartz schist, calc-silicate and marble, and metaconglomerate, Rahaman, (1976). Locally, the study site is underlain mainly by quartzite with tongues of Pan-African Intrusions (Figure 2a). Hydrogeologically, the study area is drained mainly by the Onyami river drainage system. The river is characterized by perennial flow with considerably reduced flow volume in the dry season. It is fed by numerous tributary streams and streamlets, which are

largely seasonal. Onyami River is found farther west of the study area.

MATERIALS AND METHODS

a. Vertical Electrical Sounding. The Vertical Electrical Sounding (VES) technique was adopted for detailed subsurface investigation of the area using the Schlumberger configuration (Figure 3). Basically, Schlumberger array entails passing of electric current into the ground via a pair of non-polarizing steel electrodes (current electrodes, C₁ and C₂) and measurement of the resulting potential drop (pd) across another electrode pair (Potential electrodes, P₁ and P₂); all four electrodes being linearly and symmetrically displaced about a fixed centre. Depth penetration is gained by successive symmetrically increasing the half current electrode spacing about a fixed centre, with potential electrodes being temporarily fixed; and their spacing (P₁ to P₂) expanded only when the measured potential difference (pd) becomes too small for accurate determination. A six point-per-decade method was employed, which involves taking six measurements within AB/2 of 1-10 m, 10-100m etc. The equipment used was ABEM 1000 Terrameter, with relevant accessories. Fifteen (15) Vertical Electrical Sounding (VES) locations were occupied together with spreads along two profiles. The maximum half current electrode separation (AB/2) of 165m was attained where the space permitted, which was deemed sufficient in allowing a good depth of penetration for the suspected subsurface feature under investigation. Signal Averaging System, a method whereby consecutive readings are taken automatically and the results are averaged continuously, was employed where needed during data acquisition, for noise cancellation and thus, signal to noise ratio improvement. The field measurements operation was followed by the computation of the apparent resistivity, a quantity which depends on the current input, the measured potential difference (V) and electrode spacing factor (the geometric factor), K. The apparent resistivity, a measure of the formation's (subsurface materials) electrical response is then plotted on a double logarithmic graph against the half current electrode spacing to produce the 'observed/field curve' which was manually cleaned of spurious spikes and eventually iteratively interpreted using the main ideas of (Zohdy, 1989), to gain insights into the existing subsurface geological settings.

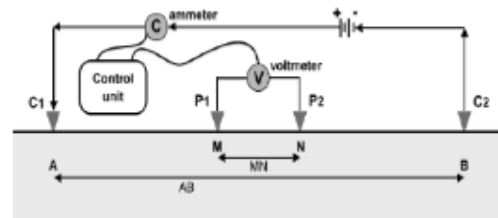


Fig 3: Schematic Diagram of Schlumberger Array: C₁ and C₂ = current electrodes; P₁ and P₂ = potential Electrodes; AB = current electrodes separation; MN = potential electrode separation. (after Jeffrey *et al.*, 2008).

b. Dipole-Dipole Array: The Dipole-Dipole (2-D resistivity) imaging survey involves the injection of direct current into the subsurface with current dipole (C1 and C2) and measurement of the resulting ground voltage with the potential dipole (P1 and P2). The array (Figure 4) delineates the subsurface in both vertical and horizontal domains (Ward, 1990). Increasing the separation between the dipole pairs (C1–C2 and P1–P2) results in increasing depth of investigation. The expansion factor (n) was varied from 1 to 5, and inter-electrode pair spacing (a) of 10 m was employed. The maximum length of the traverse profiled was 400m. The apparent resistivity (ρ_a) in Ohm-meter at each dipole separation was calculated using equation 1 (Barker, 2007; Seidel and Lange, 2007).

$$\rho_a = \pi n a (n + 1)(n + 2) \left(\frac{\Delta V}{I}\right) \dots \dots \dots (1)$$

Where a = inter-electrode spacing, n = expansion factor, and

$$\left(\frac{\Delta V}{I}\right) = \text{Resistance (R) measured during data acquisition.}$$

The apparent resistivity values obtained were plotted on a depth section along intersecting 45° beneath the centre of the dipoles (Figure 4). To overcome the problem of non-uniqueness (i.e. many models fitting the data equally well), a smoothness-constrained least-squares inversion was applied using a 2-D inversion algorithm, DIPRO for Windows, version 4.01 (Kigam, 2001). In this 2-D inversion, five iterations were performed because at the fifth iteration with RMS error less than 6% the observed resistivity data and the calculated responses tend to remain the same. After the completion of the inversion processes, a 2-D resistivity depth section was obtained which represents a high resolution subsurface image of geological settings along the profile (Anudu *et al.*, 2012).

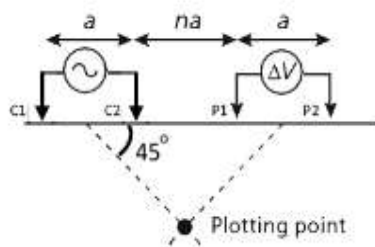


Fig 4: Schematic Illustration of the Dipole-Dipole Array. C1 and C2 = Current Electrodes (Current Dipole); P1 and P2 = Potential Electrodes (Potential Dipole); n = Number of times the potential dipoles were shifted from current dipoles; a = Electrode spacing.

RESULTS AND DISCUSSIONS

a. Dipole-Dipole: The results of the Dipole-dipole traverses are presented with three 2-D pseudosections for each traverse. The first is the acquired field (raw)

data, the second is the algorithm generated theoretical data, while the third is the inverted 2-D model. All the interpretation and geologic inferences were made from the third inverted 2-D pseudosections. This was carried out with respect to elevation in meters as shown on the left and right flank of the 2-D pseudosections and also in order to correlate it with the geoelectric pseudosections generated from VES data. The elevation ranges from 250m to 300m (which makes the depth of interpretation to be about 50m). For easy interpretation, colour bands along with contour lines were used to depict various resistivity values from where geologic inferences were made. In the inverted 2-D pseudosections, relatively low resistivity values are shown in blue and green colours, while high resistivity values are in red and purple. The first dipole-dipole carried out along Bokeshimi Street (Figure 5) generally has near-surface low resistivity values except between 20-30m (horizontal scale) on the interpreted inverted 2-D pseudosection. The fractured zone exist around 280m to 310m along the inverted 2D resistivity pseudosection with low resistivity values around 129Ωm (Figure 5) and extends beneath the subsurface to a depth beyond 30m. The second dipole-dipole profile was conducted along Amore road (Figure 6), it has the same colour representation as the first dipole-dipole. The inverted 2-D resistivity pseudosection exhibits significant variations of near surface resistivity values along the section. Relatively high resistivity values (>1000Ωm) were observed around 30-50m and 80-110m along the profile, these zones coincide with places where outcrop of basement rocks were observed. But at 240-250m, the interpretation gave a shallow low resistivity value. Also in this section, the red and purple colours were interpreted to be the fresh/dry basement area, while weathered/fractured basement were inferred from the green (and admixture of green and yellow) colour at greater depth.

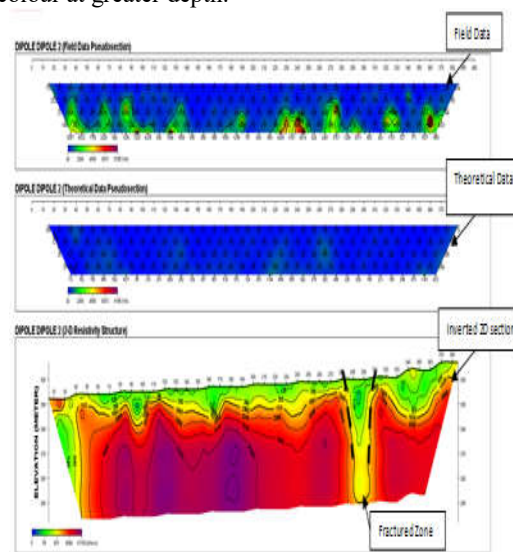


Fig 5: Bokeshimi Dipole-Dipole Pseudosections: Top (Field Data); Middle (Theoretical Data) and Bottom (2-D Resistivity Structure).

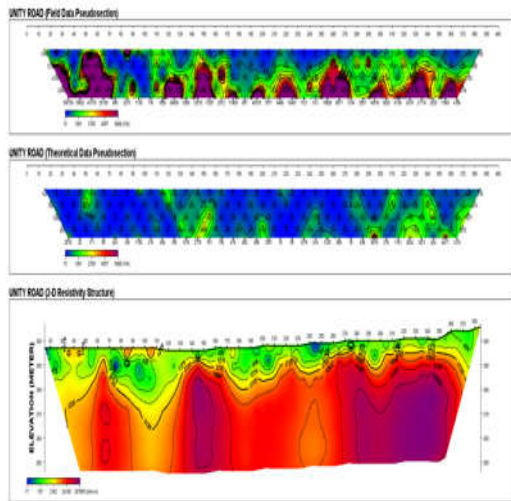


Fig 6: Amore Dipole-Dipole Pseudosections: Top (Field Data); Middle (Theoretical Data) and Bottom (2-D Resistivity Structure).

b. Vertical Electrical Sounding (VES): Figure 7 shows the typical curve types observed during quantitative interpretation. The VES curve types observed in the area under study are KH, A, H, AK, QH and KA. Fifty-three percent (53%) of all the sounding curves are KH, 13% are H and A curve type, while AK, QH and KA make up 7% as shown in the pie-chart in Figure 8. Therefore, KH is the predominant curve type. The geoelectric parameters of the subsurface layers were obtained from interpreted VES data, and presented in Table 1. Three to six geoelectric layers were generated from the quantitative interpretation of the vertical electrical sounding curves. These geoelectric layers were later resolved into three to six geologic layers which included the topsoil, clayey layer, lateritic sand, the weathered rock, fractured rock and fresh basement rock.

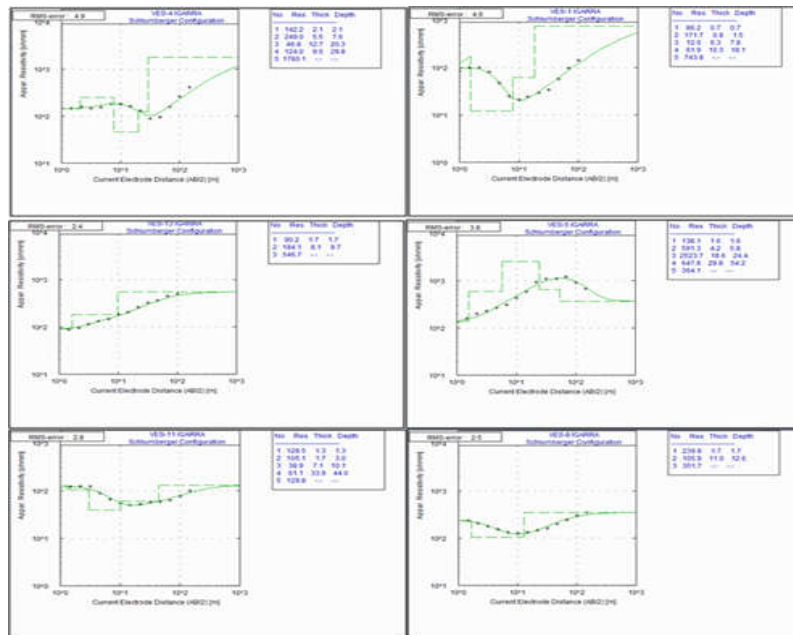


Fig 7: Some of the Interpreted Typical Vertical Electrical Sounding (VES) Curves.

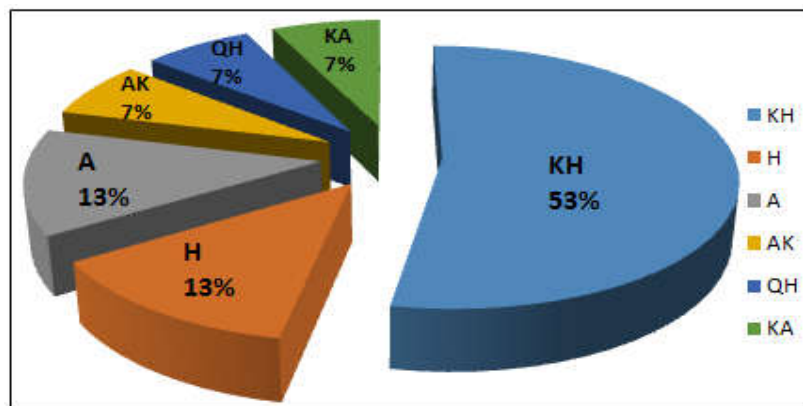


Fig 8: Classification of Curve Types Observed Around Igarra Area.

Table1: Geoelectric Parameters and Curve Types of VES in Igarra.

VES number	Layer Resistivity (Ωm) ($\rho_1/\rho_2 \dots \rho_n$)	Depth (m) ($d_1/d_2 \dots d_{n-1}$)	Inferred Lithology	Curve Type
1	88.6/171.7/12.0/61.9/743.8	0.7/1.5/7.8/18.1	T/CS/WB/FB/FBR	KH
2	90.6/ 23.1 / 847.1	1.1 / 6.2	T/WB/FBR	H
3	86.3/ 96.5/ 572.8	1.4/ 8.7	T/WB/FBR	A
4	142.2/249.0/46.8/124.0/1780.1	2.1/7.6/20.3/29.8	T/LS/WB/FB/FBR	KH
5	138.1/591.3/647.8/364.1	1.6/5.8/24.4/54.2	T/LS/WB/FB/FBR	AK
6	409.7/807.1/511.2/224.3/357.6	1.2/3.3/9.6/64.4	T/LS/WB/FB/FBR	KH
7	225.4/359.4/40.5/54.6/218.1	1.2/3.5/13.7/37.7	T/CS/WB/FB/FBR	KH
8	239.9/105.9/351.7	1.7/12.6	T/WB/FBR	H
9	157.9/598.1/79.7/185.2/480.9	0.5/1.8/7.6/29.7	T/LS/WB/FB/FBR	KH
10	285.9/625.8/211.9/324.7/441.0	1.4/6.7/27.8/62.6	T/LS/WB/FB/FBR	KH
11	128.5/105.1/38.9/61.1/129.8	1.3/3.0/10.1/44.0	T/CS/WB/FB/FBR	QH
12	53.5/58.8/28.0/37.6/119.3	1.5/2.9/10.4/31.6	T/CS/WB/FB/FBR	KH
13	90.2/184.1/546.7	1.7/9.7	T/LS/FBR	A
14	131.4/423.8/228.2/998.4/725.5	0.7/2.6/8.0/29.2	T/CS/WB/FB/FBR	KA
15	385.8/909.0/312.7/540.6/621.5	0.7/6.2/35.5/67.7	T/LS/WB/FB/FBR	KH

T = Topsoil; S = Clayey Sand; LS = Lateritic Sand; WB = Weathered Basement; FB = Fractured Basement; FBR = Basement Rock.

c. *Geoelectric Sections:* The summary of the interpretation results of VES 1, 2, 3, 4, 5, 6 and 15 in Igarra carried out along Bokeshimi Street in terms of the geoelectric/geologic layering is presented as a geoelectric pseudosection in Figure 9, from the Southwest to Northeast direction. The section was generated using the geoelectric parameters beneath each VES stations and elevation of each VES positions in order to show the topographic variation along the profile lines. The first layer consists of topsoil (which is clayey to lateritic), with resistivity varying from 86 Ωm in VES3 to 385 Ωm in VES15, while thickness ranges from 0.7m in VES1&15 to 2.1m in VES4. The second layer consists of lateritic sand and is predominant around the northeast zone, characterized by resistivity value varying from 249 Ωm at VES5 and 909 Ωm at VES15 location, with thickness ranging from 2.1m at VES6 to 5.5m at VES 4&15 locations. The second layer is underlain by weathered basement at the northeastern area. However, the weathered basement is directly underneath the first layer at the southwestern area. This layer has significant interpreted thickness of 18.6m and 29.3m under VES5 and VES15 respectively and is believed to hold potentials for groundwater accumulation. The layer resistivities vary between 12 Ωm and 2523 Ωm at VES1 and VES5 locations. Fracture basement was delineated beneath the weathered basement and it is predominant towards the northeastern part of the geoelectric section. However, it only existed underneath VES1 in the southwestern area. It has resistivity values between 124 Ωm and 540 Ωm and thickness varying from 9.5m beneath VES4 and 54.8m underneath VES6. The last layer is interpreted as the fresh basement rock throughout this geoelectric section. The second geoelectric section (Figure 10) was conducted along Amore road. It was generated using geoelectric parameters of VES 12 down to VES 7 in the southwest to northeast direction. The topsoil, defined by layer resistivity values varying from 53 Ωm at VES12 to 239 Ωm at VES8 consists of clayey sand and laterite. The second layer has clayey sand beneath VES 11 and VES12 with resistivity values of 105 Ωm and 58 Ωm respectively. VES7, VES9 and VES10 consist of

lateritic sand in the third layer, having resistivity value of 359 Ωm , 598 Ωm and 652 Ωm respectively. The fractured basement in this geoelectric section exists underneath VES7, VES11 and VES12. The interpreted fractured basement thickness at VES7 is 24m while it is 33.9m underneath VES11 and 21.2m beneath VES12. The last layer underneath the fractured/weathered basement is the fresh basement rock with the highest resistivity of 480 Ωm .

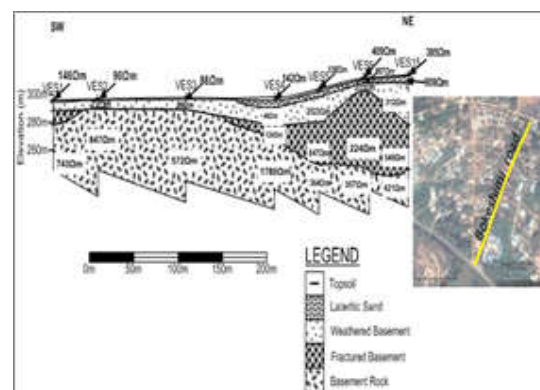


Fig 9: Geoelectric Pseudosection along Bokeshimi Road, Igarra. VES Stations are Located along the Indicated Yellow Line.

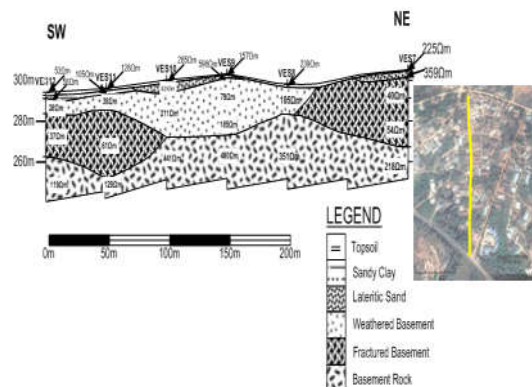


Fig 10: Geoelectric Pseudosection along Amore Road, Igarra. VES Stations are Located along the Indicated Yellow Line.

d. Combined 1-D and 2-D Correlation Panels for Fracture Detection: Figure 11 shows the result of the combined geoelectric pseudosection obtained from VES data and 2-D inverted section generated from the dipole-dipole array carried out along the same traverse on Bokeshimi Street in Igarra, southwestern Nigeria. It shows that on both sections the fracture zone existed in the southwest area but the lateral extent is relatively small compared to the fracture zone in the northeast area where it is laterally extensive. The interpretation of the results of the geophysical studies undertaken at Igarra has shown that the northeastern flank of the study area along Bokeshimi Street (close to local government secretariat) is possibly underlain by fractured basement which could serve as favourable habitat for groundwater accumulation.

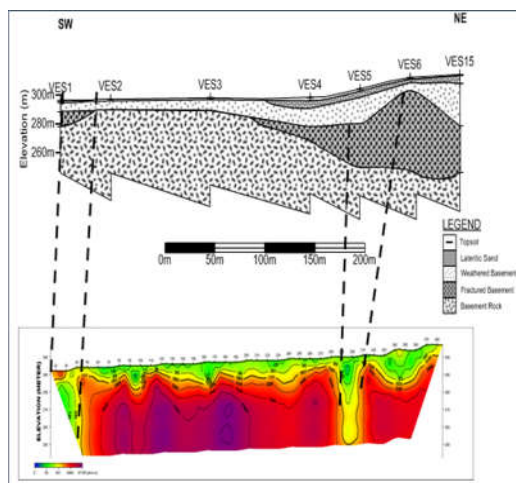


Fig 11: Fracture basement comparison within the VES generated geoelectric pseudosection and the inverted 2-D resistivity profile from Dipole Dipole.

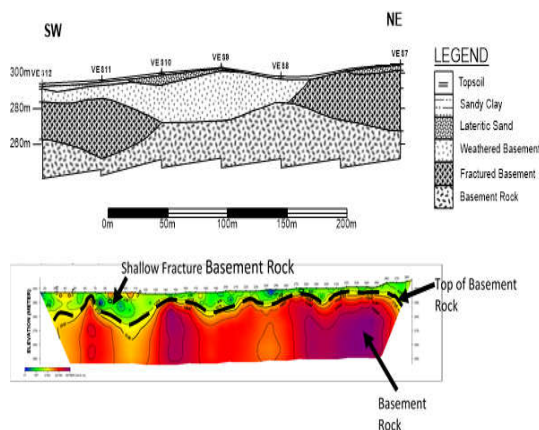


Fig 12: Fracture basement comparison within the VES generated geoelectric pseudosection and the inverted 2-D resistivity profile of Amore road.

Therefore any proposed borehole sited within the fractured zones that is well constructed will optimally abstract groundwater for domestic and or industrial use. Furthermore, figure 12 shows the correlation of geoelectric pseudosection and 2D resistivity structure

along Amore road in the study area. In the 2-D pseudosection the thick black broken line represent the top of the basement rock, while the basement rock is represented in red and purple colours. The green colour shows part of the fractured basement rock which seems to be shallow along this profile.

Conclusion: The 1-D and 2-D integrated resistivity investigations carried out in Igarra, southwestern Nigeria has revealed that there is high possibility of a fractured basement around the northeastern part of the survey area. It has also revealed that the overburden materials consist of topsoil, sandy clay, lateritic sand and weathered basement. The fractured windows have good groundwater potentials, so also is the zone of thick overburden materials. These findings have once again demonstrated the rapid and cost effectiveness of resistivity methods for groundwater development.

REFERENCES

- Adeoye-Oladapo, OO; Oladapo, MI (2011). Geoelectric investigation of Owuruwuru dam site, Ikere Ekiti, Southwestern Nigeria. *J. of Geol. and Min. Research Vol. 3(12)*, pp. 325-340
- Adepelumi, AA; Akinmade, OB; Fayemi, O (2013). Evaluation of groundwater potential of Baikin, Ondo State, Nigeria using resistivity and magnetic techniques: A case study. *Universal J. of geosci. (2)*: 37-45, 2013.
- Anifowose, AYB; Bamisaye, OA; Odeyemi, IB (2006). Establishing a solid mineral database for part of Southwestern Nigeria, Geospatial World Newsletter. (<http://www.geospatialworld.net>).
- Anudu, GK; Essien, BI; Obrike, SE (2012). Hydrogeophysical investigation and estimation of groundwater potentials of the Lower Palaeozoic to Precambrian crystalline basement rocks in Keffi area, North-central Nigeria, using resistivity methods. *Arab J Geosci (2014) 7:311–322*. DOI 10.1007/s12517-012-0789-x.
- Barker, RD (2007). Electrical resistivity methods for borehole siting in hardrock region. In: Thangarajan M (ed) Groundwater: resource evaluation, augmentation, contamination, restoration, modeling and management. *Springer, Dordrecht*, p 357.
- Boesse, S; Ocan, O (1992). Geology and evolution of the Ife-Ilesha Schist belt, southwestern Nigeria. In: Benin-Nigeria Geotraverse international meeting on the Proterozoic Geology and Tectonics of high grade terrain. IGCP 215, pp. 123-129.
- El-Kaliouby, H; Abdalla, O (2015). Application of time-domain electromagnetic method in mapping saltwater intrusion of a coastal alluvial aquifer, North Oman. *J. of App. Geoph. 115 (2015) 59–64*.

- Kigam (2001). DIPRO for Windows version 4.01. Processing and interpretation software for electrical resistivity data. KIGAM, Daejeon.
- Jeffrey, EL; Jared, DA; Bethany, LB (2008). Resistivity profiling for mapping gravel layers that may control contaminant migration at the amargosa desert research site, Nevada. U.S. Geological Survey, Reston, Virginia: 2008.
- Oluyide, PO (1988). Structural trends in the Nigerian basement complex. In: Oluyide, PO; Mbonu, WC; Ogezi, AE; Egbuniwe, IG; Ajibade, AC; Umeji, AC (Eds), Precambrian Geology of Nigeria. Geological Survey of Nigeria, Kaduna, pp.93-98.
- Odeyemi, IB (1999). Late-Proterozoic metaconglomerates in the schist belt of Nigeria: Origin and tectonostratigraphic significance. *J. of Technoscience. Vol 3, pp.56-60.*
- Offodile, ME (1983). The occurrence and exploitation of groundwater in Nigerian basement rocks. *J. Min. Geol.* 20(1 & 2):131-146.
- Olorunfemi, MO; Fasuyi, SA (1993). Aquifer types and the geoelectric/hydrogeologic characteristics of part of central basement terrain of Nigeria (Niger State). *J. of Afr. Earth Sci.* 16(3):309-317.
- Oyawoye, MO (1964). The geology of the basement complex. *J. of Nigeria Min., Geol. and Metallurgy. Volume 1, pp. 87-102.*
- Rahaman, MA (1976). Review of the Basement Geology of SW Nigeria in Geology of Nigeria. Elizabethan Publishing Company, Nigeria. pp. 41-58.
- Rahaman, MA (1989). Review of the basement geology of Southwestern Nigeria. In: Kogbe, CA (ed) Geology of Nigeria, 2nd Revised edn. Rockview Nigeria Limited, Jos: pp 39-54.
- Satpathy, BN; Kanungo, BN (1976). Groundwater exploration in hard-rock terrain: A Case Study. *Geoph. Prosp.* 24(4):725-736
- Seidel, K; Lange, G (2007). Direct current resistivity method. In: Environmental geology: handbook of field methods and case studies. Springer, Berlin, p 1339.
- Salami, SA; Babafemi, EM (2017). Hydrogeophysical survey for groundwater investigation in Ogbe, Akoko-Edo area of Southwestern Nigeria. *Nigerian J. of App. Sci. Vol. 35, pp 31-42*
- Soupios, PM; Georgakopoulos, P; Papadopoulos, N; Saltas, V; Andreadakis, A; Vallianatos, F; Sarris, A; Makris, JP (2007). Use of engineering geophysics to investigate a site for a building foundation. *Journal of Geophysics and Engineering. J. Geoph. Eng.* 4 (2007) 94-103
- Ward, SH (1990). Resistivity and induced polarisation methods. In: Anudu, GK; Essien, BI; Obribe, SE (2012). Hydrogeophysical investigation and estimation of groundwater potentials of the Lower Palaeozoic to Precambrian crystalline basement rocks in Keffi area, North-central Nigeria, using resistivity methods. *Arab J Geosci (2014) 7:311-322*
- Zohdy, A (1989). A new method for the interpretation of Schlumberger and Wenner sounding curves. *Geophysics V.54 N2 PP 245-253.*